**International Journal of Mechanical Engineering and Technology (IJMET)**
Volume 10, Issue 01, January 2019, pp. 306–315, Article ID: IJMET_10_01_031
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=10&IType=1
ISSN Print: 0976-6340 and ISSN Online: 0976-6359



# HEAT TRANSFER COEFFICIENT ENHANCEMENT IN NATURAL CONVECTION FROM HORIZONTAL RECTANGULAR FIN ARRAYS WITH PERFORATIONS

**Dr. N.P. Salunke**
Principal, SVKM's IOT, Dhule,, Maharashtra, India.

**I.N. Wankhede**
Assistant Professor, GCE, Nagaon, Maharashtra, India.

**ABSTRACT**

*The overall convection heat transfer coefficients for long horizontal rectangular fin arrays are low because the surfaces in the inner region are poorly ventilated. In this study, perforations through the fin base are introduced to improve ventilation with cold air from below the fin base. Aluminum fin arrays with length L= 380mm, fin height H = 38mm, fin thickness $t_f$ = 1mm, and fin spacing S = 10mm are analyzed experimentally and numerically using ANSYS 14.0 so as to obtain the temperature distribution along the fin height and fin length. In this work the fin array configurations are tested experimentally with two different heater input as 50W and 65W. The heat transfer coefficient for fin array with perforations in fin base increased by the enhancement factor of 1.49 and*

*1.42 as compared to fin array without perforation with 50W and 65W heater input respectively. The heat transfer coefficient for the same fin configuration is also increased with increase in heater input from 50W to 65W. Experimental and numerical results for the temperature distribution show a difference of 5-9%. The distribution of heat flux obtained with ANSYS 14.0 quantitatively follows the trend of the same reported in the literature review.*

**Key words:** Perforation, Fins, Steady state, Natural convection.

**Cite this Article:** Dr. N.P. Salunke and I.N. Wankhede, Heat Transfer Coefficient Enhancement in Natural Convection from Horizontal Rectangular Fin Arrays with Perforations, *International Journal of Mechanical Engineering and Technology* 10(1), 2019, pp. 306–315.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=10&IType=1

# 1. INTRODUCTION

High–power LED is a promising technology for future lighting application since it can save energy and has a long life time. To obtain more lumen, powerful electric current of LED chips grows at a faster rate nowadays. However, with the high power LED chips, generally nearly 80% of the input power is transformed into heat while the rest is converted into light, and this leads to a series of penalties [1].Therefore, to gain a dependable and perfect product with good enactment, thermal management of high power LEDs is very important. To solve the LED heat dissipation, some methods can be employed, such as improving in chip luminous efficiency, which will drastically reduce the heat generation, improving in the package, which will reduce the inner thermal resistance, or improving in the heat transfer coefficient of heatsink, such as micro jet cooling system, heat pipe [2], etc. But these techniques are rarely put into use because of reasons including cost factors, high reliability and maintenance requirements. The life of LED lamp is usually about 100,000 hours, and it works in the outdoor environment. Therefore, the heat sink of high-power LED is usually cooled through natural convection.

The thermal management of LEDs for general illumination applications is of primary importance to their dependability and efficiency. While considering the thermal management of high power LED's, two main encounters must be taken into account. First, while a single device consumes relatively low power, large heat fluxes, of the order of 300W/cm2 or greater, exist at the die level. Such high heat fluxes frequently require exceptional heat spreaders at the die level in order to help disintegrate such concentrated heat loads. Second, since the luminous output of an individual high power LED is insufficient to replace the traditional light source, multiple LED's are necessary for general radiance. With the use of large LED arrays, it is possible to generate large heat loads at the system level which can cause challenges for overall heat degeneracy, especially when cooling requirements call for passive methods. These two challenges work together to cause higher LED die temperatures. It has been predicted previously that the lifetime of a device decays exponentially as the temperature increases. This can result in a lifetime decrease from 42,000 h to 18,000 h when the device temperature increases from $40^0$C to $50^0$C [1].

Christensen and Graham [1], investigated the package and system level temperature distributions of a high power (>1W) light emitting diode (LED) array using numerical heat flow models. Xiang-Rui, et.al. [2], studied the natural convection heat transfer enactment of horizontal heat sink by numerical simulation. Huang et al. [6], introduced perforations through the fin base to improve ventilation with cold air from below the fin base. Harahap and McManus [8], observed the flow field of horizontally based rectangular fin arrays for natural

convection heat transfer to determine average heat transfer coefficients. The effects of fin length, fin height, fin spacing, shape of perforation, fin orientation, etc. too was reported extensively in the literature. Luo et.al. [25], presented a design and optimization method of horizontally- located plate fin heat sink to improve the heat dissipation of high power LED street lamps.

# 2. EXPERIMENTAL SETUP AND METHODOLOGY

From the literature review, for the heat sinks currently utilized in the high powered street LED's, a stagnation zone is formed at the symmetry center of the fins which causes a problem in air the circulation ultimately affecting the heat dissipation capacity of the heat sink. Therefore there should be the proper provision for air to be drawn. There is wide scope of study w.r.t this parameter. For high power LED street lamps [25] specified, the general

dimensions of horizontal plate-fin heat sinks under natural convection. By considering the strength, manufacturability and performance of the heat sinks, the suggested dimensions are as follows:

(a) Fin spacing S = 1 - 15 mm, (b) fin height H = 25 - 50 mm,

(c) Fin thickness $t_f$ = 1 - 3 mm, and (d) fin length L = 150 - 500 mm, depending on the total power of the LED lamps.

Within the range of these dimensions, the dimensions selected for heat sink are as that of [6], for the numerical study to check effect of total perforation length and perforation pattern on the enhancement mechanism of horizontal rectangular fin arrays are used as heat sinks for high powered street LED's. The fin arrays will be produced from solid rectangular bar with dimensions 380x65x48 mm. With the help of numerical study efforts were intended to perform an experimental study for the same dimensions utilized so as to check the effect experimentally for the optimized perforation pattern given [6]. Rectangular fin arrays without perforations and with perforations are manufactured with the dimensions mentioned above are as shown in Fig.2.1

**Figure 2.1** Fin Array Geometries

Both the fin configurations were analyzed for temperature distribution along the fin length and fin height with ANSYS

14.0 and experimental set up was formed. Experimental set up mainly consists of fin array geometry, rectangular duct and various instruments for measuring the ambient temperature, fin temperature and the power input for the heater.

**Figure 2.2** Experimental Set-up and Instrumentations

For each of the fin arrays, the power input will be adjusted to the required heater input initially and the base-plate will be heated for about 2 hours to get the uniformity in temperature. The temperatures will then be measured by means of thermocouples located on the surface of fin. In order to decide whether the fin array is at steady-state or not, the

thermocouple readings are taken at ten minute intervals and this condition is assumed to be reached when the difference between two successive readings of each thermocouple is more or less constant and repeatability of readings is noticed [16]. The surface temperature $T_s$, the ambient temperature Ta and the power input to the heater Q will is recorded at steady-state. The testing procedure mentioned above is repeated for the 65 W power input for both the fin arrays.

## 3. RESULTS AND DISCUSSION

Performance of heat sink for street LED's was experimentally analyzed by incorporating the fin base with and without perforations. Here experimental observations were noticed for both the types of optimized fin array configuration for different heater inputs as 50W and 65W and changes in temperature distribution along the height and length of fin were recorded to check the effect on heat dissipation capacity of heat sink. Temperature distribution along the height and length of fin was obtained with help of ANSYS 14.0 to compare the experimental results. Distribution of total heat flux along the fin was also obtained with ANSYS 14.0 [28].

Experimentally obtained Temperature distribution along the length and height of fin for the plain fin array with 50W and 65W heater input respectively are as shown in Fig. 3.1 to Fig.3.4. Same can be obtained with ANSYS 14.0 as shown in fig.3.5 and Fig.3.6

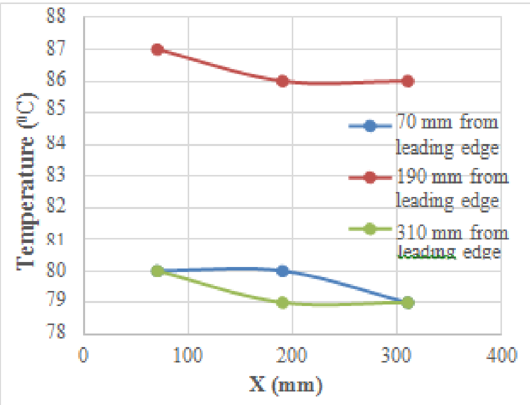


Fig.3.1: Temperature distribution along the height at different locations on fin length for plain fin array @50 W heater input

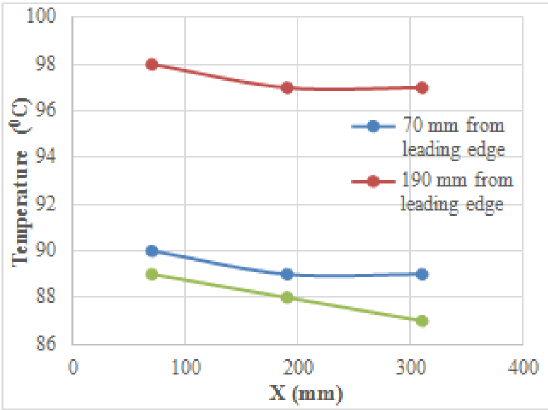


Fig.3.3: Temperature distribution along the height at different locations on fin length for plain fin array @65 W heater input

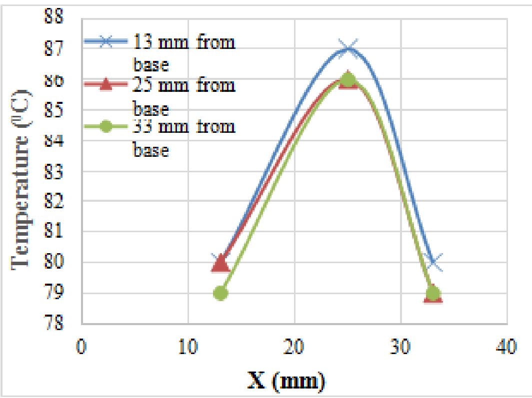


Fig.3.2: Temperature distribution along the length at different locations on fin height for plain fin array @50 W heater input

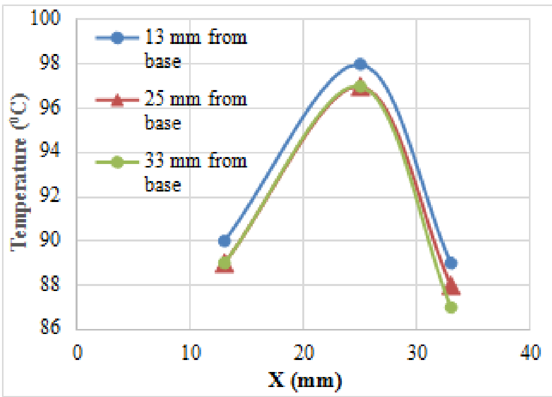


Fig.3.4: Temperature distribution along the length at different locations on fin height for plain fin array @65 W heater input

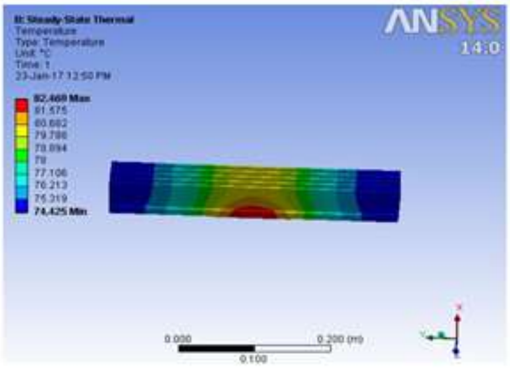


Fig.3.5: Temperature contour for plain fin array @ 50 W heater input

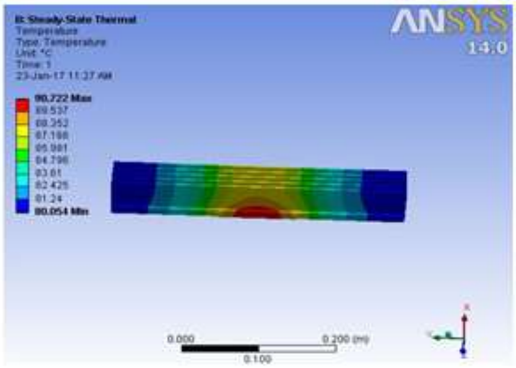


Fig.3.6: Temperature contour for plain fin array @ 65W heater input

As the heat is supplied at the center portion of base plate of fin array and allowed to transfer it by conduction through the whole fins, temperatures at the corners of fin array was noticed to be less as compared to the values near the center. It also varies along the height of fin as the heat is being transferred to the atmosphere by the mode of convection through fin tip. If we change the heater input to 65 W, there is a noticeable change of near about 11$^0$C at the middle section and of about 8$^0$C at the corners. Also enhancements in temperatures are recorded in numerical results obtained with ANSYS14.0. As compared to numerical results obtained for 50W input it shows an increment of about 8$^0$C and 5$^0$C in maximum and minimum temperatures of fin array respectively.

Now the same procedure is repeated for perforated fin array configuration to obtain the temperature distribution along the fin height and fin length at respective heater inputs. fin array configuration with the same 50W heater input. Numerical results obtained for perforated fin array also shows decreasing trend of temperatures compared with plain fin array.

Now the heater input is enhanced to 65W for perforated configuration. Temperature distribution obtained experimentally and numerically for this heater input is as shown in fig.3.10 to 3.12. different locations of fin length for perforated fin array @ 50W heater input

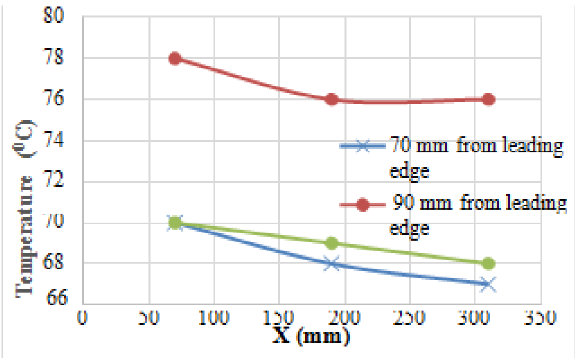


Fig.3.7: Temperature distribution along the height at different locations of fin length for perforated fin array @ 50W heater input

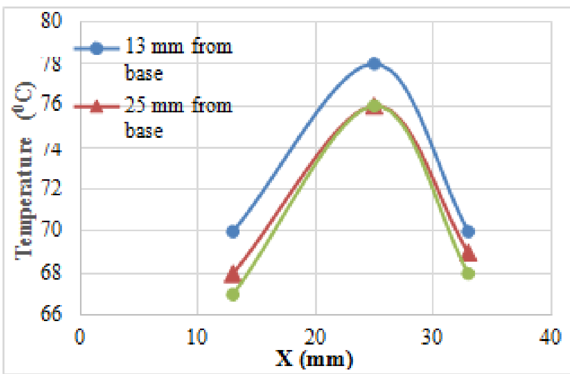


Fig.3.8: Temperature distribution along the length at different locations of fin height for perforated fin array @ 50W heater input

It was noted that, the temperatures obtained for perforated fin configuration dropped by 9$^0$C and 11$^0$C as compared to maximum and minimum temperature level obtained for plain fin array configuration with the same 50W heater input. Numerical results obtained for perforated fin array also shows decreasing trend of temperatures compared with plain fin array

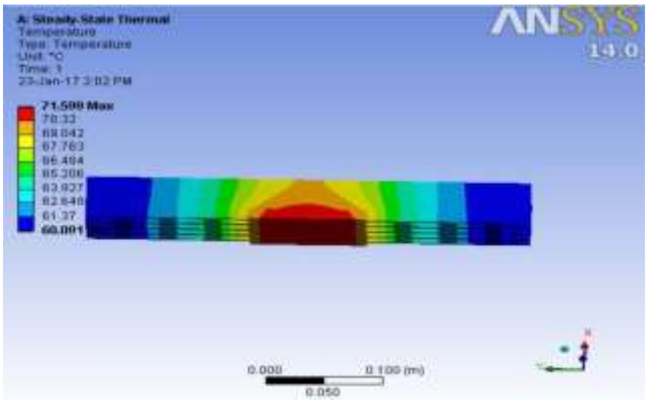


Fig.3.9: Temperature contour for perforated fin array@ 50W heater input

Now the heater input is enhanced to 65W for perforated configuration. Temperature distribution obtained experimentally and numerically for this heater input is as shown in fig.3.10 to 3.12.

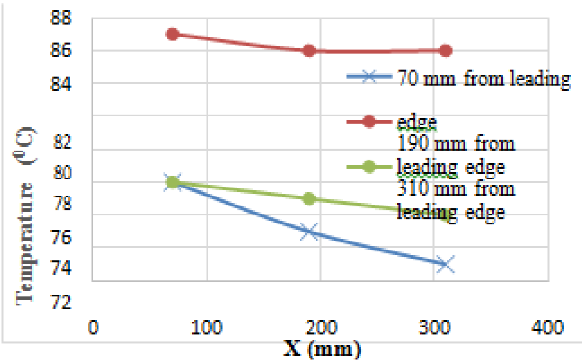


Fig.3.10: Temperature distribution along the height at different locations of fin length for perforated fin array @ 65W heater input

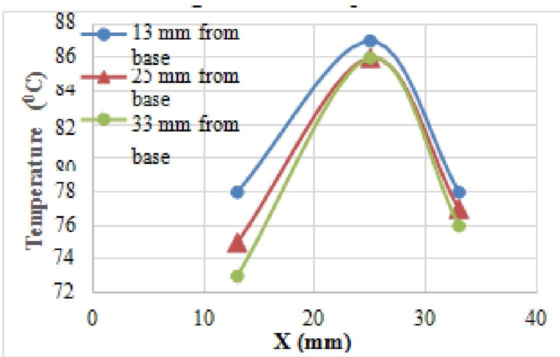


Fig.3.11: Temperature distribution along the length at different locations of fin height for perforated fin array @ 65W heater input

Temperature distribution for perforated fin configuration with 65W input obtained with ANSYS 14.0 is shown in Fig. 3.12. As compared to temperatures obtained for plain fin array with 65W heater input, there is a drop of 11$^0$C and 15$^0$C in maximum and minimum temperature.

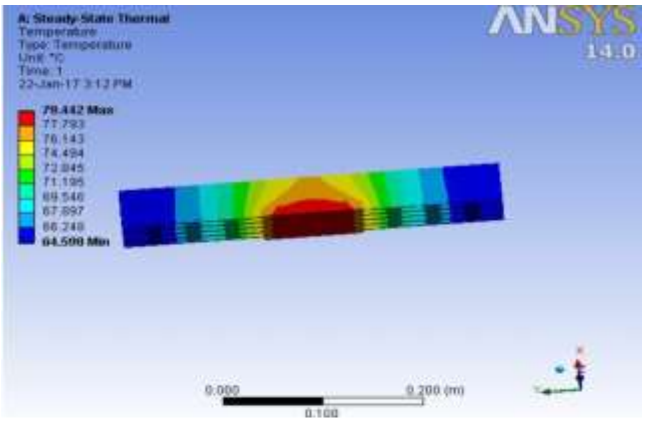


Fig. 3.12: Temperature contour for perforated fin array

@ 65W heater input

With the help of temperature obtained during the experiment, heat transfer coefficient is calculated using standard correlations for natural convection [27]. The value obtained experimentally is given to ANSYS 14.0 as an input for steady state thermal analysis which produces the temperature distribution and distribution of total heat flux. Table 3.1 contains both experimental and numerical results of temperature distribution and gives the percentage error between them. It is observed that, the percentage error between experimental and numerical results varies from 5 to 9 %. Distribution of heat flux along the fin is also obtained using ANSYS 14.0 and it also qualitatively follows the trend with numerical results obtained for the same configuration of fin array [6].

By calculating the heat transfer coefficient value for each of the fin array configuration with different heater inputs, it is observed that the heat transfer coefficient increases for perforated fin array configuration with the enhancement factor of 1.49 as compared to fin array without perforation. It also increases with the increase in heater input. Fig.3.13 shows the increasing trend for heat transfer coefficient with heater input for fin arrays with perforation and without perforation.

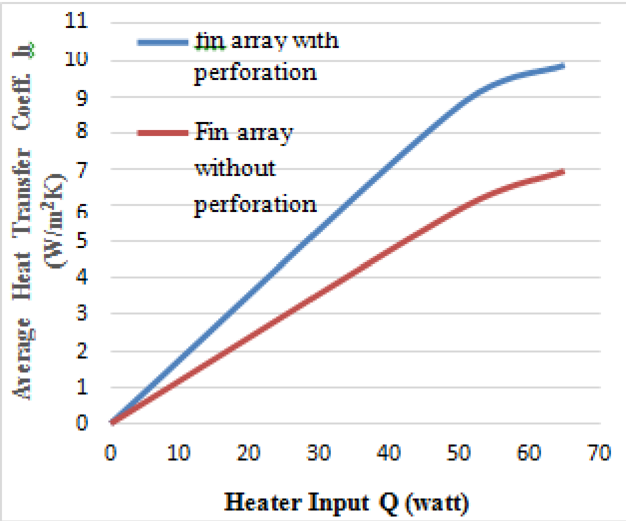


Fig. 3.13: Variation of heat transfer coefficient with heater input for fin arrays with and without perforation

Table.3.1 Comparison of Experimental and Numerical Results

| **Sr. No.** | **Type of Fin Geometry** | **Heater input (watt)** | **Maximum and Minimum Temperatures obtained for fin geometry ($^0$C)** | | | | **Error (%)** | |
|---|---|---|---|---|---|---|---|---|
| | | | **Experimental** | | **Numerical** | | | |
| | | | **$T_{max.}$** | **$T_{min.}$** | **$T_{max.}$** | **$T_{min.}$** | **$T_{max.}$** | **$T_{min.}$** |
| 1 | Without Perforation | 50 | 87 | 79 | 82.469 | 74.425 | 5.21 | 5.79 |
| | | 65 | 98 | 87 | 90.722 | 80.054 | 7.43 | 7.98 |
| 2 | With Perforation | 50 | 78 | 68 | 71.599 | 60.091 | 8.21 | 8.68 |
| | | 65 | 87 | 73 | 79.442 | 64.598 | 8.69 | 8.76 |

## 4. CONCLUSIONS

In this work, fin-base perforations are introduced for large horizontal fin arrays to improve ventilation with cold airflow from below the fin base. For both the fin array configurations, the mechanism of enhancement of heat dissipation has been discovered by examining the temperature distribution along the fin height and fin length. The effect of perforation is investigated with respect to different heater inputs. The following conclusions are reached.

- For the fin array with perforation, there is noticeable drop in maximum and minimum temperature along the height of fin as compared to fin array without perforation.
- A temperature drop of 10-16% is noticed between the fin configurations with and without perforation which clearly indicates enhanced heat transfer due to inclusion of perforations in fin base.
- For a fin array with uniform heat applied on the bottom surface at its middle part and longitudinal perforations outside the heat source region, significant heat transfer enhancement by a factor of
- 1.49 is achieved with improved ventilation in the fin channels
- The convective heat transfer coefficient for the perforated fin array increases with increasing heater input.
- The percentage error between experimental and numerical results obtained with ANSYS 14.0 lies between 5 to 9 %.

## REFERENCES

[1] A. Christensen and S. Graham, "Thermal effects in packaging high power light emitting diode arrays," *Applied Thermal Engineering,* vol. 29, pp. 364-371, 2009.

[2] M. Xiang-rui, M. Xin-ling, L. Ji-fu and W. Xin-li, ", “A Study on Improving in Natural Convection Heat Transfer for Heat Sink of High Power LEDs”," *Advanced Materials Research,* Vols. 383-390, pp. 6834-6839, 2011.

[3] K. E. Starner and H. N. McManus, "An Experimental Investigation of Free Convection Heat Transfer from Rectangular Fin Arrays," *Journal of Heat Transfer,* pp. 273-278, 1963.

[4] C. W. Leung and S. D. Probert, "Thermal Effectiveness of Short-Protrusion Rectangular, Heat-Exchanger Fins," *Applied Energy,* vol. 34, pp. 1-8, 1989.

[5] C. W. Leung, S. D. Probert and M. J. Shilston, "Heat Exchanger: Optimal Separation for Vertical Rectangular Fins Protruding from a Vertical Rectangular Base," *Applied Energy,* pp. 77-85, 1985.

[6] G. J. Huang, S. C. Wong and C. P. Lin, "Enhancement of natural Convection heat transfer from horizontal rectangular fin arrays with perforations in fin base," *International Journal of Thermal Sciences,* vol. 84, pp. 164-174, 2014.

[7] J. R. Welling and C. B. Wooldridge, "Free Convection Heat Transfer Coefficients from Vertical Fins," *Journal of Heat Transfer,* pp. 439-444, 1965.

[8] F. Harhap and H. N. Mcmanus, "Natural Convection Heat Transfer from Horizontal Rectangular Fin Arrays," *Journal of Heat Transfer*, pp. 32-38, 1967.

[9] C. D. Jones and L. S. Smith, "Optimum Arrangement of Rectangular Fins on Horizontal Surfaces for Free Convection Heat Transfer," *Journal of Heat Transfer,* pp. 6-10, 1970.

[10] N. D. Fitzroy, "Optimum Spacing of Fins Cooled by Free Convection," *Journal of Heat Transfer*, pp. 462- 463, 1971.

[11] A. Bar-Cohen, "Fin Thickness for an Optimized Natural Convection Array of Rectangular Fins," *Journal of Heat Transfer*, pp. 564-566, 1979.

[12] C. W. Leung, S. D. Probert and M. J. Shilston, "Heat Exchanger Design: Thermal Performances of Rectangular Fins protruding from vertical or horizontal rectangular bases," *Applied Energy,* vol. 20, pp. 123- 140, 1985.

[13] C. W. Leung, S. D. Probert and M. J. Shilston, "Heat Transfer Performances of Vertical Rectangular Fins Protruding from Rectangular Bases: Effect of Fin Length," *Applied Energy,* vol. 22, pp. 313-318, 1986.

[14] C. W. Leuang and S. D. Probert, "Heat-Exchanger Design: Optimal Uniform Thickness of Vertical Rectangular Fins Protruding Perpendicularly Outwards, at Uniform Separations, from a Vertical Rectangular 'Base," *Applied Energy,* vol. 26, pp. 111- 118, 1987.

[15] Y. M. Ko, C. W. Leung and S. D. Probert, "Steady – State Free-Convective Cooling of Heat Exchangers with Vertical Rectangular Fins: Effect of Fin Material," *Applied Energy,* vol. 34, pp. 181-191, 1989.

[16] H. YuÈncuÈ and G. Anbar, "An Experimental Investigation on Performance of Rectangular Fins on a Horizontal Base in Free Convection Heat Transfer," *Heat and Mass Transfer,* vol. 33, pp. 507-514, 1998.

[17] H. Yüncü and A. Güvenc, "An Experimental Investigation on Performance of Rectangular Fins on a Vertical Base in Free Convection Heat Transfer," *Heat and Mass Transfer,* pp. 409-416, 2001.

[18] M. Mobedi and H. Yu¨ncu, "A Three Dimensional Numerical Study on Natural Convection Heat Transfer from Short Horizontal Rectangular Fin Array," *Heat and Mass Transfer,* vol. 39, pp. 267-275, 2003.

[19] S. Yildiz and H. Yu¨ncu¨, "An Experimental Investigation on Performance of Annular Fins on a Horizontal Cylinder in Free Convection Heat Transfer," *Heat and Mass Transfer* , vol. 40, p. 239– 251, 2004.

[20] R. Jain and M. M. Sahu, "Comparative Study of performances of Trapezoidal and Rectangular fins on a Vertical base under free convection heat transfer," *International Journal of Engineering Research & Technology,* vol. 2, pp. 2278-0181, 2013.

[21] M. I. Al-Widyan and A. Al-Shaarawi, "Numerical Investigation of Heat Transfer Enhancement for a Perforated Fin in Natural Convection," *International Journal of Engineering Research and Applications,* vol. 2, pp. 175-184, 2012.

[22] A. H. AlEssa, A. M. Maqableh and S. Ammourah, "Enhancement of natural convection heat transfer from a fin by rectangular perforations with aspect ratio of two," *International Journal of Physical Sciences,* vol. 4, pp. 540-547, 2009.

[23] S. C. Wong and G. J. Huang, "Parametric study on the dynamic behavior of natural convection from horizontal rectangular fin arrays," *International Journal of Heat and Mass Transfer,* vol. 60, pp. 334- 342, 2013.

[24] G. J. Huang and S. C. Wong, "Dynamic characteristics of natural convection from horizontal rectangular fin arrays," *Applied Thermal Engineering,* vol. 42, pp. 81- 89, 2012.

[25] X. Luo, W. Xiong, T. Cheng and S. Liu, "Design and Optimization of Horizontally-located Plate Fin Heat Sink for High Power LED Street Lamps," in *Electronic Components and Technology Conference,* 2009.

[26] A. Dvinsky , A. Bar-Cohen and M. Strelets, "Thermo fluid Analysis of Staggered and Inline Pin Fin Heat Sinks," in *International Society Conference on Thermal Phenomena,* 2000.

[27] F. P. Incropera and D. P. Dewitt, Fundamentals of Heat and Mass Transfer, *New York: John Wiley & Sons, 1990.*

[28] P.V. Baviskar, K.A.Saner and N.P.Salunke, "To analyse the effect of varying fin shapes for Microprocessor cooling,", *International Journal of Innovative Research in Science Engineering and Technology,* 2016/4/4,Vol.5 , Issue 4.

[29] Prof. N. M. Shinde Dr. N. P. Salunke, "Improvement of Gas Turbine Performance Based on Rib Augmented Cooling Systems: A Review*", International Journal of Scientific Research in Science, Engineering and Technology*, 2018/2/2, Vol.4, Issue 1.